4.2-5.47

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF ENTOMOLOGY

FOREST INSECT INVESTIGATIONS

WESTERN PINE BEETLE BIOLOGICAL STUDIES

MODOC NATIONAL FOREST

SEASON OF 1928

by

H. L. PERSON
Assistant Entomologist

[redacted]
SB
763
C2 M6
1928 A

Berkeley, California
June 1, 1929

U. S. GOVERNMENT PRINTING OFFICE: 1928 J 76133

OUTLINE

Page

Table of Contents - 1

I Introduction - 2

II Studies in Biological Control - - - - - - - - - - - - - - - - 3

Methods Used in 1928 Studies - - - - - - - - - - - - 4
Data from Cage Material - Tree L-14 - - - - - - - - 6
Sample Counts from Tree L-14 - - - - - - - - - - - - 8
Average Brood Counts, Tree L-14 - - - - - - - - - - 9
Miscellaneous Data from Other Trees- - - - - - - - 10
Conclusions from Studies in Biological Control- -12
Further Studies in Biological Control- - - - - - - 13
Summary -14

III Causes of Decline of the Western Pine Beetle Infestation on the Badger Unit- - - - - - - - - - - - - - 15

Increased Resistance of the Trees - - - - - - - - -16
Abundance of Insect Enemies of the Western Pine Beetle- 16
Summary -20

IV Life History of the Western Pine Beetle, Modoc Area- 21

Life History Studies- - - - - - - - - - - - - - - - - -21
Summary- 24

Photo No. 1- - - - - - - - - - - - - - -25

Chart No. 1 - - - - - - - - - - - - - - 26

National FS Library
USDA Forest Service

MAR 2 4 2014

240 W Prospect Rd
Fort Collins CO 80526

WESTERN PINE BEETLE BIOLOGICAL STUDIES

MODOC NATIONAL FOREST - SEASON OF 1928

Introduction

The importance of the western pine beetle problem in the Modoc area of northeastern California, together with the variety of types of infestation found there, makes this area particularly favorable as a center of work for biological studies. Not only are the most severe types of western pine beetle infestation found in this area, but the low endemic type as well. Then too the recent timber sale development on the Badger Unit, which is largely the result of severe bark beetle losses, makes it desirable to have our field station so located that some of the studies can be "tied in" with this operation. Consequently the field base for the biological studies was moved from the Cascadel area of the Sierra National Forest to the Fandango area of the Modoc National Forest during May, 1928.

As a considerable amount of time was spent in establishing a new field camp and laboratory and in making an extensive reconnaissance of the Modoc area, the amount of time spent on the biological studies was necessarily limited. The studies on tree selection, attraction and secondary Coleoptera associated with the western pine beetle have been separately reported on, by Person, Mirov and Struble respectively.

This report will include the results of preliminary studies of (1) biological control, with special emphasis on the protection of the most important natural enemy of the western pine beetle, the clerid, Enoclerus lecontei Wolc. (Thanasimus nigriventris Lec.); (2) factors affecting the decline of the western pine beetle infestation on the Badger Unit; and (3) the life history of the western pine beetle on the Modoc area.

STUDIES IN BIOLOGICAL CONTROL

One of the serious disadvantages of our present methods of artificial control by burning the infested bark is that most of the beneficial insects are destroyed with the bark beetles. Some improvement has been made in this regard by protecting the stumps from control fires and so saving the mature clerid larvae that migrate to the base of the tree, and also by the discontinuance of summer burning of infested trees in which the clerids are particularly abundant. But there is still room for a great deal of improvement. It is the purpose of our biological control studies to develop a method that will result in the destruction of a high percentage of the bark beetles and at the same time permit the escape of the most important beneficial insects.

During the past several years a considerable amount of work has been done on the biology of the insect enemies of the western pine beetle, especially the clerid, E. lecontei, which was found to be the most important natural enemy of the western pine beetle. This work suggested the possibility of treating trees in such a manner that a high percentage of the western pine beetle broods would be killed without much injury to the clerids. The basis for this line of attack is the much greater motility of the clerid larvae as compared to D. brevicomis larvae, which enables them to escape from conditions which prove fatal to the western pine beetle.

This difference in the migratory ability of the two insects may be taken advantage of either by modifying our present burning methods in spring and fall control against the overwintering broods, or by developing methods of summer control by exposure of the infested trees to conditions that will prove fatal to most of the western pine beetle broods but not to the clerids.

The preliminary studies of 1928 were confined to the second method, that of creating conditions that would favor the clerids at the expense of the bark beetles. There is nothing new about the methods of treatment used, except that the effect of the different methods on the beneficial insects was considered as equal in importance to the effect on the bark beetles. Dr. Craighead has directed the experimentation in this field for the last few years in an effort to find a more satisfactory method of control. Falling trees in different positions, girdling, cutting out logs and other methods have been tried under a variety of conditions, but none of these methods has resulted in a bark beetle mortality which in itself was high enough to make it worth while.

We are now making a different approach to the problem. Our aim is not to get a complete kill of the bark beetles, but rather to reduce them enough to change the balance in favor of the clerids.

Because of the abundance of clerids in the summer generation trees, as well as the danger in burning during the fire season, summer control work has been largely discontinued. In some cases this is unfortunate because the beetle population, which is greatly reduced during fall and spring control, has a chance to build up during the summer months and so maintain itself at a higher level than if summer control was also practised. Summer control is especially desirable on recreational areas and wherever values warrant the most effective possible control, and wherever there is a possibility of extermination. It also has possibilities in connection with logging control projects, such as the present Pickering operation on the Modoc.

Sun curing has been used for summer control in a number of cases, and is more satisfactory than burning; it should be used in preference wherever possible because it eliminates the fire hazard and also allows many of the beneficial insects to escape. But although this method, under favorable conditions of temperature and exposure, is quite effective in destroying the D. brevicomis broods, it kills many of the beneficial insects as well.

Methods Used in 1928 Studies

Our 1928 studies were intended to determine the effect, on both D. brevicomis and the clerid C. lecontei, of felling and exposing the infested trees in different ways and under different conditions. Because of the limitations of time and equipment only one tree, L-14, was studied in detail. Supplementary data were taken from other trees as time permitted. Most of the work was done on the main summer generation (1928) trees, which usually have two or three times as many clerids as the late fall or overwintering generation.

Before this study could be satisfactorily pursued, it was necessary to devise a rearing cage that could be used to determine the contents of infested bark without resorting to laborious and inaccurate methods, such as shaving the bark and noting the contents. Suggestions by Craighead and Miller were worked out, with the result that a very satisfactory rearing cage was developed.

This rearing cage consists of a galvanized iron cylinder, 30 inches high and 18 inches in diameter, with an inverted truncate-cone-shaped bottom with an opening about two inches in diameter. A friction type cover is used, in the center of which is an opening two inches in diameter covered with copper straining cloth. The cover is slightly convex. All joints were carefully soldered and a strip of cotton was used as a gasket to prevent any leakage aroundthe top. The cages were set upright on a rack, and the emergence was collected in wide-mouthed gallon candy jars which were kept partly filled with water. Strips of cotton batting were also used to close the opening between the top of the jar and the cone-shaped bottom of the cage. The set-up of cages is shown in Photos 1 and 2. It was found that the moisture and temperature in these cages stayed quite close to the normal for standing trees, so that the development of the broods was very nearly the same as in standing trees. The air circulation can be regulated by changing the

size of the openings, and the temperature could be modified by changing the amount of shade. The material was collected from the jars every two or three days by running the water through a fine sieve. This material was sorted by species and preserved in alcohol.

This type of cage, if properly made and set up, is very nearly "insect tight", even for the very smallest forms. Large numbers of newly-hatched clerid larvae, as well as many very small histerid and staphylinid larvae and dipterous and hymenopterous maggots, were collected. A cage of this type will hold from 15 to 20 square feet of yellow pine bark of average thickness.

Study of Tree L-14. This tree was a Class IV tree, 24 inches in diameter and 95 feet in height. It was one of a group of eight medium-sized trees that were attacked by the western pine beetle during the last part of June and the first part of July. This group was located on the Lassen Creek Unit in a pure yellow pine type of Site III. The topography is nearly level, with a slight slope toward the southeast. The elevation is about 5,000 feet.

When this tree was felled, on July 24, the entire trunk except 25 feet of the top was found to be infested with a good brood of D.brevicomis, mostly large larvae with a few pupae. The top was infested with Ips oregoni larvae and pupae. The trunk was cut into sections of different lengths, each of which received different treatment according to the following:

1. Fifteen square feet of infested bark was peeled from the main trunk immediately after felling and put in a metal cage for rearing. This bark was taken in the form of strips completely encircling the trunk--one strip two feet in width and five feet in length at 15 feet above the base, and the other one foot in width and five feet in length at 25 feet above the base. The insects in this bark were collected as they emerged from the bark and counts made of the total number of clerid larvae in the bark and the total emergence of D.brevicomis adults. These figures were used to represent normal, undisturbed conditions, and were used as a basis for comparison of the different methods of treatment used.

2. All the bark on the five-foot log between 20 and 25 feet from the base was peeled and spread out on the ground, exposed to full sunlight. This represented the regular sun-curing method.

3. The basal log, 15 feet in length, was cut and left unpeeled flat on the ground exposed to full sunlight except for part of the morning and late afternoon, when some shade was cast by nearby trees.

4. A log six feet in length was cut out between 30 and 36 feet from the base, and left unpeeled and exposed to full sunlight. This section was left lying across logs so that it cleared the ground by 18 inches.

5. A 30-foot log between 36 and 66 feet from the base was also left 18 inches clear of the ground but lightly covered with brush, which protected it from direct sunlight.

All the above sections were left in the conditions described for seven days, from July 24 to August 1, 1928. This happened to be the hottest part of the summer, as is evident from the temperature curve in Fig. 1. (This curve is based on the records from the hygrothermograph at the weather station maintained during the season at the Buck Creek field station. The instrument was checked frequently with a corrected thermometer.) On August 1, 16 square feet of bark was cut from a band around the middle of each section and caged separately, by sections, in the metal cages.

At this time a sample count was also made of one square foot of bark from the top, bottom and each side of each section. The purpose of these counts was to determine the amount of brood, both living and dead, in the bark at the time the bark was caged, and also to secure a basis for comparing the results of exposure on the different parts of each log. If a sufficient number of cages had been available the bark could have been segregated and caged according to location on the log as well as by method of treatment.

Collections were made from the caged material from July 25 to September 5. The D.brevicomis emergence occurred between August 6 and August 31. The collections were made from two to five times a week, and the number of D.brevicomis and clerids that emerged from each cage was totaled.

Results and Discussion - Tree L-14. A comparison of the collections of both D.brevicomis and the clerid from the different sections is given in Table 1.

TABLE 1

Data from Cage Material - Tree L-14

Sec. No.	Treatment	Basis Sq.ft.	D. brevicomis Total	per Sq.ft.	Mortality %	E. leconteï Imm.	Mat-ure	Total	per Sq.Ft.
1	Normal; caged imm. after felling	16	1235	84.5	0	162	164	326	21.7
2	Peeled; sun-cured; seven days	16	39	2.6	97	56	26	63	4.2
3	Unpeeled; exp. on ground seven days	16	434	27.0	68	62	105	167	10.4
4	Unpeeled; exp. 18" off ground 7 ds.	16	329	20.5	78	85	125	210	13.1
5	Unp., shaded; 18" off ground 7 ds.	16	419	26.0	69	92	153	245	15.3

From this table it is evident that the exposure of infested logs for a week or more during the hottest part of the summer reduces the emergence of D.brevicomis very decidedly. It is also evident that the mortality of D.brevicomis is much greater proportionately than the mortality of the clerid. Using the emergence from the bark that was caged without any exposure as the normal for standing trees, it was found that the mortality above normal varied in the treated sections from 97 per cent in the sun-cured bark to 58 per cent in the case of the unpeeled bark from the fully-exposed log lying flat on the ground. It is difficult to account for the differences in mortality with Methods 3, 4 and 5, and they may be due simply to natural variations in the broods. In any case the mortality of D.brevicomis in this experiment amounted to approximately 70 per cent of the total emergence from the unexposed bark.

It should be explained that whereas the difference in emergence between the normal, unexposed bark and the exposed bark represents roughly the mortality due to the exposure in the case of D.brevicomis, this is not true in the case of the clerid. The D.brevicomis broods are unable to leave the bark until they emerge as adults, so that the emergence represents the total effective progeny. The clerids, however, may leave the bark in the larval stage and pupate in the ground. Because of this habit it is not possible to determine how many clerids survive by counting only the number that remain alive in the bark. Consequently the number of clerids given in Table 1 for Sections 2 to 5 does not represent the total number that survived, but rather the number that remained alive in the bark. Since the number that migrate is variable it is not known how many actually survived; but the small number of dead clerids found in Sections 3, 4 and 5 shows that only a small percentage of the total were killed in these sections --probably not over 10 per cent.

Referring again to Table 1 we find that in any one of the methods 3, 4 or 5--which represent the average conditions that a tree would undergo naturally if felled in an open yellow pine stand--the mortality of the D.brevicomis broods would average about 70 per cent of the normal emergence, and the mortality among the clerids would be about 10 per cent of the total normal emergence. On this basis the effective progeny would number approximately 24 per square foot for D. brevicomis and 18 or 19 per square foot for the clerid.

Feeding studies with this clerid showed that each adult might easily destroy between 25 and 50 bark beetles if available; so it is very probable that the clerids that survived would not only destroy the bark beetles that survived from the same bark areas but would also destroy many more that might emerge from untreated trees. Consequently this method of control (by exposure of the unpeeled logs) would be much more effective, where applicable, than control by burning.

Method 2, typical sun-curing, would also be much better than burning because the mortality of D.brevicomis is about the same for both methods, and the clerid mortality with the sun-curing would be at least 25 or 30 per cent less than where the bark was burned. There are at least two reasons why the mortality of the clerids would be much higher with the sun-curing method than with any of the other exposure methods. The direct mortality is greater because the peeled bark would heat much more quickly than the unpeeled bark on the logs, and so the clerids would have less chance to escape before the lethal temperature was reached; and the indirect mortality from starvation and other causes would be greater in the sun-cured bark because the young clerid larvae which escape from the bark have little chance of finding the food and shelter necessary for the completion of their development. In the case of the unpeeled bark on the exposed log, however, the larvae can crawl from the top or south side of the log, where the temperatures may become too high, to the north side or the bottom, where the food supply and shelter is favorable to their continued development. The mature larvae would probably survive in either case; so when sun-curing is practised it should be delayed as long as possible without allowing the escape of the bark beetles, so that a higher percentage of the clerids will have become mature larvae.

It is obvious that the temperature and moisture and consequently the mortality on top of an exposed log would be very different from that on the sides or bottom. The temperature and moisture differences for different parts of the log were not determined, but differences in mortality were, by making a brood count on a one-square-foot sample area from the top, bottom and each side of each of the sections 3, 4 and 5. The results of these counts are given in Table 2.

TABLE 2 - Sample Counts from Tree L-14

Sec. No.	Treatment	Position on Log	Clerids per sq.ft: Living	Dead	D.brev. per sq.ft.: Living	Dead
	Exposed log on	Top	10	5	5	60
	ground	Bottom	21	0	35	0
3		N. side	16		40	
		S. side	12		61	
		Average:	15.0		35.0	
	Exposed log 18"	Top	7		0	24
	above ground	Bottom	7		62	
4		N. side	17		30	
		S. side	11		29	
		Average:	10.5		23	
	Lightly-shaded	Top	7		8	11
	log 18" off	Bottom	11		37	
5	ground	N. side	15		22	
		S. side	23		27	
		Average:	14		23	
	Grand Average		13.2		28.7	

As would be expected, the highest mortality occurred on top of the log in all three sections. In the case of D.brevicomis this represents a direct killing of the brood, from lethal temperatures. The number of dead larvae found when the bark was shaved up is only a small part of the total number killed, for many of the larvae become so shriveled that it is almost impossible to count them with the methods used. The low clerid counts on the top sections were due partly to direct killing but mostly, it is believed, to the migration of the larvae to other parts of the log or to the ground. The migration to the sides of the logs is indicated by the higher average clerid counts at these locations; and it is known that many of the mature larvae crawl to the ground and pupate, because a number of them were found under stones, in decaying pieces of wood or bark buried in the duff, or in clayey lumps of soil near the infested trees or logs.

Table 3 was prepared to show the average counts for the three methods by position on the log.

TABLE 3

Average Brood Counts for Sections 3, 4 and 5 - 1-14

Position on Log:	Average No. of Individuals per sq.ft. after Exposure	
	D.brevicomis	E.lecontei
Top	4	8
Bottom	45	13
N. side	37	16
S. side	39	15

The fact that the number of living clerids found was lowest on top of the log, highest on the sides and intermediate on the bottom suggests the following explanation: Probably about 25 to 30 per cent of the total number of clerids left the log to pupate in the ground (this is a reasonable assumption on the basis of other studies with this clerid). Then the number of clerids found on the bottom of the logs represents the average number left after the "extra-log" migration. A number of the clerids on top of the log were driven away by the heat and most of these probably crawled to the sides of the logs, thus leaving the lowest number on the top and the highest on the sides. This, of course, is a purely hypothetical explanation which should be confirmed by further study.

The most significant point in Table 3 is that the number of living clerids on the tops of the logs was twice as great--even without including the clerids which migrated--as the number of surviving bark beetles. This, together with the fact that the greatest number of clerids is found on the sides, whereas the greatest number of bark beetles was found on the bottoms of the logs, shows that where practical a very effective control could be secured by leaving logs exposed in one position for a week and then turning them completely over, so that the bottom would become the top, and leaving them for another week. Under favorable conditions such treatment would undoubtedly result inthe survival of more clerids to the square foot than bark beetles.

Miscellaneous Data from Other Trees

In the preceding we have considered the data from the one tree, L-14, only. No other tree was studied in as much detail, but brood counts and observations from a number of other trees tend to confirm the results from Tree L-14 and also indicate some of the limitations of the methods used, especially in regard to the length of exposure and the effect of differences in slope and air temperature. Most of the data were obtained in much the same way as the data in Tables 2 and 3. In general the infested tree to be studied was felled and a square foot of bark from the top, another from the bottom and one from each side were carefully shaved up and a count made of the D.brevicomis, clerids, and any other important species found. This first count was made very soon after the tree was felled in order to determine the normal brood before exposure. Then the tree was left, either fully exposed or partially shaded, for from three days to as many weeks, and a second count made from the same log positions from which the first counts were made. A summary of the data from these trees is given in Table 4.

This table, because of the miscellaneous nature of the data included, is of little value except to supplement other observations. The so-called normal brood counts on these trees which were made at different stages of the larval and pupal development cannot be compared directly with later counts when the brood is at a more advanced stage. There is a progressive mortality of all organisms from the time the egg is laid until the mature adult stage is reached. In the case of D.brevicomis about 500 eggs to the square foot are laid in a normal attack, and the emergence from these 500 eggs averages about 60 to 80 adults (per square foot). It is then obvious that the younger the brood the greater the number of individuals, other things being equal. The first counts from Trees L-1 and L-4 were made when the broods were in the half-grown larval stage, and we should expect the large number of individuals which were found--514 for L-1 and 300 for L-4 per square foot. The clerid larvae start to develop later than the D.brevicomis broods, so that many of them were not found in the first counts. This accounts for the small clerid counts at these early stages as compared with later counts.

These two trees, L-1 and L-4, were part of a group of five trees killed late in June by the western pine beetle. They were located on an exposed point with a southerly exposure. Tree L-1 was partially shaded, so that part of the brood remained alive even on the top of the log, though it was greatly reduced. The clerids were most abundant on the sides of the log, which agrees with what was found in Tree L-14. L-4 was fully exposed and raised a few inches from the ground. All the D.brevicomis brood on the top of the log was killed, and all the clerids were killed or driven away but one. The largest broods were found on the north side and the bottom.

TABLE 4

MISCELLANEOUS DATA FROM OTHER TREES

Tree No.	Date Felled	Counts made	Treatment	Position on Tree	No. Days Exposed	Basis SqFt.	Db. stage	Db. per Sq.Ft.		E. leconteï per Sq.Ft.	
								L	D	L	D
L-1	7/19	7/19	Not exposed	15'-20'	—	1	L. brown	514	0	2	0
		7/25	Partial shade	20' SW	7	1	L.& P.	50		24	
				W	7	1	"	177		29	
				N	7	1	"	157		15	
				E	7	1	"	184		26	
		8/ 9	"	20' Top	20	1	P., N.A.	21	60	9	
				NW	20	1	"	97	3	19	
				Bot.	20	1	"	40		4	
				SE	20	1	"	89		15	
L-4	7/18	7/16	Not exposed	15'-40'	—	1	L. brown	300		4	
		8/ 8	Fully off grd.	20' Top	23	1	P., N.A.	0	104	1	1
				NW	23	1	"	78	69	13	0
				Bot.	23	1	"	81	8	4	0
				SE	23	1	"	87	122	5	0
L-16	7/26	7/26	Not exp.	20'	—	5	L., P.	157		25	
		8/14	25% shade on ground	20' Top	18	1	P., N.A.	0	51	7	0
				N	18	1	"	26	25	21	0
				Bot.	18	1	"	12	4	12	0
				S	18	1	"	21	18	7	0
L-17	8/ 8	8/ 8	Not exp.	20' TOP	—	4	P., N.A.	132		16	
		8/15	Fully On ground	20' Top	7	1	N.A., Rm.	11		5	3
				N	7	1	"	125		4	
				Bot.	7	1	"	89		2	
				S	7	1	"	49		5	1
L-18 Exp. Purp. Tree	9/11	9/11	Not.exp. Par.Shade Off Grd.	20' TOP	—	4	L,P,N.A.	130		5	
				Top	4	1	"	152		8	
				E	4	1	"	153		7	
				Bot.	4	1	"	68		2	
				S	4	1	"	42			
L-25	9/ 7	9/ 7	Not.exp.	20' Top	—	1	L,P,N.A.	81		2	
				E	—	1	"	213		3	
				Bot.	—	1	"	107		4	
				S	—	1	"	116		7	
		9/12	NE exp. part sh. off gr.	20' Top	5	1	L,P,N.A	147		9	
				E	5	1	"	183		3	
				Bot.	5	1	"	61		5	
				S	5	1	"	123		5	

Trees L-16 and L-17 were in the same group as L-14. L-16 was felled at about the same time as L-14 and the results are quite similar, though L-16 was exposed for 18 days between counts. One hundred per cent of the D.brevicomis brood on the top of the log was killed, and the broods on the sides and bottom showed a marked reduction as compared with unexposed sections. The clerids evidently found the top and south side too hot and so concentrated on the north side or migrated from the log.

Tree L-17 was not felled until August 8. At that time the brood was so far advanced that many of the new adults were able to emerge before a lethal temperature was reached, especially on the north side and the bottom. A marked reduction of the brood is noted on the top and south side, but otherwise the emergence was probably about normal for that tree. The small number of clerids found is at least partly due to the more advanced stage, which made it possible for a greater number to migrate in the mature larval stage before the counts were made.

Trees L-18 and L-25 are both second-generation trees, in which the number of clerids is usually small. (The explanation for this is given in a former report already referred to.) L-18 was partly shaded from nearby trees and was exposed for only four days between counts. As the temperature for this period was comparatively low (see Fig. 1) there is no evidence of sun-killing and the emergence was probably little affected by the exposure. Tree L-25 was exposed for only five days on a northeast slope, also during comparatively cool weather, and no brood reduction was noted. In fact, the counts after exposure averaged higher than before, due to the natural variability of adjacent samples.

Conclusions from Studies in Biological Control

It is evident that because of the small amount of data and the natural variability of the samples it is not possible to draw many definite conclusions. However, it is believed that we may accept the following points as the basis for further study:

1. Beneficial clerids, because of their great motility in the larval stage and their habit of migrating in many instances as mature larvae, are able to withstand or escape from temperatures which prove fatal to the western pine beetle. Because of this there are certain temperature conditions which are fatal to D.brevicomis but not to the clerids. This was evidently the case on the top of Tree L-14, where practically 100 per cent killing of the western pine beetle broods was accomplished without much injury to the clerids.

2. The low emergence from the sides and bottoms of logs exposed during the hottest weather indicates that the mortality, even on these positions, is much higher than on standing trees. Whether this is due to high temperature, excessive drying, the greater activity and concentration of predacious clerids, or a combination of these factors, is not known.

3. It is apparently possible, under favorable conditions, to reduce the D.brevicomis broods--without much injury to the clerids --until they are only slightly more numerous than the clerids. If this could be done in regular field practice it would be much more effective than our present control methods.

4. It seems evident that this method of control would be worth while only when the clerids, or other beneficial insects of similar habits, were fairly abundant, and when the air temperature, exposure and stage of brood were favorable. This practically limits this method of control to the main summer-generation trees that can be treated in July.

Further Studies in Biological Control

The studies of the past season were of only a preliminary nature, and should be continued in a more intensive manner before any recommendations can be made for the use of this method. In connection with the Pickering sale on the Badger Unit it is hoped that a large number of infested trees, cut in logging, can be studied to determine more accurately what happens in an exposed log.

The actual subcortical temperatures in different parts of a number of logs, felled under different conditions, should be determined, together with the effects on the clerids and the bark beetles. In addition, at least three trees should be studied with the use of the cages and methods used with Tree L-14. The subcortical temperatures should also be studied in these trees as in the preceding.

Summary

One of the most serious disadvantages of our present method of artificial control of the western pine beetle is that most of the beneficial insects are destroyed with the bark beetles. In order to effect a substantial reduction in the bark beetle population without serious injury to the beneficial insects some method of controlled exposure to certain conditions seems most promising.

A study of the most important beneficial insects associated with the western pine beetle--the clerid, Enoclerus lecontei Wolc.--has shown that this clerid, because of its great motility in the larval stage, is able to withstand or escape from conditions that prove fatal to D. brevicomis.

During the 1923 season some preliminary studies were made to determine the possibility of control by taking advantage of this greater resistance of the clerids to unfavorable conditions. Infested trees were felled, and logs from these trees were exposed under different conditions of shade, slope and distance above ground. These logs were studied to determine the effect on both the western pine beetle and the beneficial clerid. One tree was studied in detail and supplemental data were taken from six other trees.

Comparative counts--supplemented by rearing in special cages --from both the normal unexposed bark and the exposed bark support the following conclusions:

1. Logs may be exposed under field conditions so that a high per cent of the D. brevicomis broods are killed without serious loss of beneficial clerids. On the one tree that was studied intensively the average mortality in strips completely encircling the trunk was about 70 per cent for D. brevicomis and only about 10 per cent for the clerid. This resulted in an emergence of clerid adults almost equal to the emergence of D. brevicomis. Since each clerid could easily destroy 25 D. brevicomis adults, this result is much more satisfactory than the burning method.

2. The effectiveness of this method varies on different sides of a log, probably due principally to differences in bark temperature and moisture, though the concentration ofthe clerids is also a factor of considerable importance.

3. The low emergence from the sides and bottoms of exposed logs indicates that the mortality, even in the most protected positions, is much higher than on standing trees.

4. This method of control will probably be advisable only when the clerids, or other beneficial insects of similar habits, are quite abundant, and when the air temperature, exposure and stage of brood are favorable.

Further study is necessary before this method can be recommended for general use.

CAUSES OF THE DECLINE OF THE WESTERN PINE BEETLE INFESTATION ON THE BADGER UNIT

It became evident as the insect surveys--made annually under the direction of F.P. Keen to determine the effects of control on the Southern Oregon-Northern California Project area and to keep timber owners informed as to insect conditions in this region--progressed during the summer of 1928, that the western pine beetle infestation throughout most of northern California and southern Oregon was on the decline. The amount of this decline and the exact time that it began varied locally, but by the fall of 1928 it was general throughout the region. When the Brown's Well and Timber Mountain sample plots were cruised in September 1928, very few overwintering-generation trees were found and a very marked decline was predicted.

Although this decline was not quite so great as expected, it was very pronounced on all the 15,000 acres covered by the Pickering Company's control operation. On an average the loss on this area for the winter of 1928-29 was probably not over 25 per cent of that of the preceding winter.

Because of the limited amount of time available and the many difficulties inherent in a study of this kind, no attempt was made to compile a thorough analysis of the causes of the decline. However, observations made during the summer and bark counts in the fall of 1928 serve as a basis for suggested explanations of the decline.

On the basis of the above observations, which are supported by a number of other related studies, it is believed that the two most important causes of the decline are (1) the increased resistance of the host trees as a result of more favorable growth conditions, and (2) the unusual abundance of natural insect enemies of the western pine beetle, especially the clerid, Enoclerus lecontei Wolc.

Increased Resistance of the Trees

It is fairly well established that the resistance and susceptibility of a tree is dependent largely on its vigor or rate of growth. We may assume, then, that any pronounced increase in rate of growth indicates an increased resistance to beetle attacks.

Cores taken from average living trees in the Brown's Mountain and Timber Mountain sample plots show a decided increase in the rate of growth in 1928 over the preceding four years. (See Fig. 1.) The cause of this increased rate of growth is not known, but it is probably the combined result of the thinning of the stand by the bark beetles (between 20 and 30 per cent of the stand in this area was killed by bark beetles between 1923 and 1928) and favorable growing conditions in the spring of 1928. On the basis of precipitation alone we should expect greater growth in 1927, since the precipitation for 1926-27 was greater than that for 1927-28; but temperature conditions during the growing season were much more favorable in the spring of 1928. The spring of 1927 was very cold, whereas the spring of 1928 was unusually warm during the early months, when there was still plenty of moisture in the ground for rapid growth. In any case the growth rate was greater in 1928 than in any of the four preceding years, and consequently the resistance to attack was probably greater, so that a larger number of beetles would be required to kill each tree.

Abundance of Insect Enemies of the Western Pine Beetle

It is more difficult to obtain definite data on this point than on the preceding. However, in our work at Cascadel during the years 1925, 1926 and 1927 we obtained a considerable amount of data on the abundance of the clerid (N.leucotel Wole.), the most important natural enemy of the western pine beetle, and some comparative data were obtained in 1928 on the Modoc area.

At Cascadel it was found that the average number of clerids per square foot in 1926 and 1927 was approximately 12 in normally infested trees. On the Modoc area in 1928 the average number of clerids per square foot in the bark counted was approximately 20. This evidence would be more conclusive if the 1926 and 1927 counts could also have been made on the Modoc area, but it does indicate unusual abundance of the clerids in 1928.

This conclusion is supported by general observation; for it was noted by entomologists and foresters who visited the area in 1928 that the adult clerids were extremely abundant on newly-attacked trees. The writer has never before found the clerids as abundant as they were on the Brown's Well sample plot in July, when the principal summer-generation attack was being made.

Bark Counts of Attacks and Emergence Compared with Normal

In the preceding paragraphs we have considered two factors which are probably of primary importance in causing the decline of the infestation. An effort was made to determine the effect of these factors by making sample counts of attacks and emergence on trees killed during the summer of 1928. It is not intended that these counts furnish an adequate basis for definite conclusions; but taken with the supporting observations they suggest an explanation for the decline in infestation.

Concentration of Attacks

Related studies show that in general the number of beetles attacking per square foot increases with the vigor of the attacked tree. Trees suffering from fire or drought, or trees subnormal from any cause, usually have fewer attacks per unit of bark area than vigorous trees which may not be killed unless a very strong concentrated attack is made. We should expect, then, that the increased vigor of the stand would result in a greater number of attacks per square foot than the normal for the four preceding years.

There are two reasons for this increase in the number of attacks, which usually occurs when the growth rate of a stand is increased. One has already been given; viz., it takes a more concentrated attack to kill a more vigorous tree. The other reason for this concentration is that when the growth rate of a stand is increased the number of susceptible trees is decreased; so that with the same beetle population there is a greater concentration in these susceptible trees.

The approximate number of beetles attacking per square foot on typical trees killed by the main summer generation attack was determined by counts on 44 square feet of bark from five trees. These counts were made by Miller, Keen, Struble, Wagner and the writer in September 1928. In order to make the counts as nearly comparable as possible they were all taken from trees between 20 and 30 inches in diameter and from sections taken near the center of the D.brevicomis-infested part of the trunk. Two or more square feet were used for each sample and these were taken from four different exposures from each tree. An effort was made to select trees and bark samples as nearly as possible typical of the area.

The results of these counts are given in Table 5.

TABLE 5

Relation Between Attacks and Emergence

Tree No.	Diam.	Height	Infested Length D.b.	Infested Length Other		Size of Sample in sq. ft.			No. Attacks per sq.ft.	Average for tr.	Emergence per sq.ft.	Average for tr.
L-31	20"	90'	70'	Ips	20	Exp.	N	2	12		44	
							S	2	14		31	
							E	2	19		47	
							W	2	18	15.7	23	36.2
								8				
L-32	26"	80'	75'	I.o.	5		N	3	23		19	
							S	3	26		41	
							E	2	24		26	
							W	2	24	24.1	34	32.7
								10				
S.P. #177	20"	70'	50'	D.b. (failed)	10		N	3	10		54	
							S	3	10		57	
							E	4	10	10.0	57	50.0
								10				
S.P. #880	22"	90'	65'	Ips	25		N	2	20		22	
							S	2	12		25	
							E	2	19		52	
							W	2	14	16.1	18	29.1
								8				
SP. #881	22"	100'	60'	Ips	30		N	2	13		26	
							S	2	16		48	
							E	2	14		46	
							W	2	16	14.7	24	35.5
								8				
			Averages - - - -			Attacks - - -			16			
						Emergence- - - - - - -			36			

Note: All five of the above trees were killed during the main summer-generation attack of 1928. They had all been abandoned when examined in September.

All samples were taken between 15 and 30 feet above the base.

These counts show a variation in the number of attacks from 10 to 26 per square foot, with an average of 16. Because of the great variability in samples from different trees as well as from the same tree, no true average figure can be given for a normal attack. But when we compare this figure (16 per square foot) with the other counts of attacks that have been made since 1914 in southern Oregon and northern California we find that with one exception this is the highest average of any of the counts made. (See Table 1 in "Analysis of Brood Statistics of the Western Pine Beetle," an unpublished report by F.P. Keen, dated May 1,1928.) The counts analyzed by Keen include 54 separate lots of infested bark, or a total of 4,177 square feet. The counts were made over a period of years by different men and in different areas. These counts give from 5.5 to 15.2 attacks per square foot, with the exception of one count of 21.2 per square foot. The average number of attacks for the 4,177 square feet of bark counted was 11.6 as compared with 16 per square foot for the 1928 counts on the Brown's Well plot.

It might be contended that a count of 44 square feet of bark is insufficient as a basis for any conclusions; but since these counts are so much higher than the average of all the other counts and since all the 54 sets of similar counts were lower, with one exception, it seems safe to conclude that the number of attacks per unit of area was unusually high on the Brown's Well area in the summer of 1928.

Emergence

The counts of attacks show the concentration of the beetles in the attacked trees. Counts of the emergence were also made to show the effectiveness of the attacking beetles in producing their broods. The abundance of clerids has already been noted. This should be reflected in a high mortality of the broods during development and a low emergence in proportion to the number of beetles attacking.

The emergence counts were made from the same bark samples that were used for the counts of attacks. They were made at the same time and by the same men. The results are given in Table 5.

The emergence was found to vary from 18 to 57 per square foot, with an average of 36. Referring again to the report by Keen we find that the emergence from the 54 sets of counts varied from 29 to 168 per square foot, with an average of 63.

The emergence on the Brown's Well plot, therefore (36 per square foot) was evidently unusually low. As the number of attacks was very large this indicates a high brood mortality, which may be at least partially accounted for by the large number of clerids that were present.

Ratio of Attacks to Emergence

The number of beetles per attack is usually less variable than either the number of attacks or the emergence. Keen and Patterson have used 2.6 as the average number of beetles per attack. I have made no detailed study of this point, but in counts made at Northfork only 2 beetles per attack were found. If we use 2.25 beetles per attack, which is probably below the average, the 16 attacks per sq.ft. that we found on the

Brown's Well area would give us a total of 36 attacking beetles per square foot. This just equals the number of beetles that emerged.

Since there was no increase of brood in the trees, the infestation would be reduced by the number of beetles that were killed during flight or that made unsuccessful attacks. Mortality during flight has never been even approximately determined but must be very high, because in a normal, static infestation the emergence is usually two or three times as great as the number of beetles attacking, and the flight mortality is high enough to keep the infestation from increasing. With an equal number of beetles attacking and emerging it is evident that the flight mortality would result in a very pronounced decline in the beetle population.

Summary

The western pine beetle infestation throughout the western yellow pine stands of southern Oregon and northern California showed a marked decline during the summer of 1928. On the Badger Unit of the Modoc area this decline occurred principally during the summer, and resulted in a reduction of the infestation for the winter of 1928-29 to probably about 25 per cent of that of the preceding winter.

No thorough study was made of this problem; but on the basis of counts of attacks and emergence on typical trees, the determination of rate of growth by means of increment borings from selected trees and observations throughout the area during the summer of 1928, the following points are offered as a partial explanation for the decline:

1. Increased growth rate, resulting in a greater concentration of attacks. The growth rate of the trees of this area was greater during 1928 than for any year since 1923. The reason for this increased growth rate is problematical, but it is probably the combined result of thinning due to bark beetle killing during the preceding five years, and the favorable temperature and rain distribution during the spring of 1928.

2. The abundance of insect enemies of the western pine beetle, which resulted in a high mortality among the beetles both during development and attack. The clerid, E.lecontei, the principal natural enemy of D.brevicomis, was found to be more abundant than ever noted before.

3. In support of the two preceding points bark counts were made of attacks and emergence to determine whether the above factors--increased growth and unusual abundance of clerids--produced results that might explain the decline in the infestation.

It was found that the number of attacks was approximately 140 per cent of normal. The actual number of beetles attacking per square foot in the samples counted was 35.

The emergence from the same samples was also 36, or only 57 per cent of normal.

It is evident that since there was no increase in brood within the tree the mortality during the following period of attack and flight would result in a decided decline in the infestation.

LIFE HISTORY OF THE WESTERN PINE BEETLE
MODOC AREA - 1928

Introduction

A great many records on the life history of the western pine beetle have been taken by western workers, and the life history of this beetle has been worked out for a few localities. Under Mr. Miller's direction detailed studies were made by Keen in the vicinity of Ashland, Oregon, and by Pefson at Northfork, Calif. Less detailed studies have been made by Miller, Burke, Patterson and others at several places inOOregon and California.

These studies show a variation in the number of generations in different areas. This variation probably depends principally on the sum of effective temperatures. Keen found that at Ashland the western pine beetle had approximately 2⅔ generations a year, and Per son found that normally there were three generations a year at Northfork--two complete summer generations and one overwintering generation.

Life History Studies on Modoc Area

Although we have a large number of records, made prior to the beginning of this study, which show the stages of the western pine beetle in the Modoc area, these were never taken systematically throughout the year so as to show the rate of development or the number of generations for any one locality. Because of the lack of well-defined periods for the different events, such as was found on the Cascadel area of the Sierra Forest, it was impossible to determine the number of generations per year or the rate of development on the Modoc area without continuous study and observation in one locality.

This problem was included as one of the Modoc studies and a start made toward its solution in 1928. Because of the mixture of generations and the differences in effective temperatures from year to year, it was not possible to work out a definite life history chart in one season that would be applicable for any other year. However, on the basis of the observations made, a chart was prepared showing the probable life history by generations for 1928.

The first observations were made by Struble on 1927 overwintering broods in the vicinity of Jerome Mill. The first record of attacks for 1928 was also made in the same locality. The other observations were made on the Buck Creek Unit, the Lassen Creek Unit and the Sugar Hill Unit by both Struble and Person. A number of records were also secured from the Badger Unit which indicate an agreement in the life history on the two areas. Since the Badger Unit is approximately 500 feet lower than the Fandango areas it would be expected that the rate of development would be slightly faster on the Badger Unit; but this could not be determined from the records taken.

No attempt was made to compile a complete life history chart for all stages, because the number of records obtained was inadequate and because such a chart, based on only one season's observations, would not be applicable to any other year. An attempt was made to show how the broods were separated into generations and the rate of development of the broods in different parts of the season. The results are shown in Chart 1. This chart shows the approximate date of first attack or of first emergence or both for the trees from which records were taken. Only records from the Tandango area were included. A symbol was used to indicate date of first attacks, and the same symbol reversed to indicate the date of first emergence from the tree indicated. The numbers given are the tree numbers used to designate all experimental trees. The broods in five of the trees, numbered 1,3,4,18 and 100, were followed throughout, from attack to emergence. The broods in the other trees were noted only during attack or emergence, or near enough to these events so that the dates could be determined by comparison with other broods which were followed more closely.

It is evident from Chart 1 that attacks are made almost continuously throughout the season, and it is possible to find every stage at almost any time of theseason. Because of this overlapping or mixture of generations it is very difficult to distinguish and separate the different generations. The observations given might be interpreted as indicating simply two generations a year, the first generation attacking from May 15 to July 20 and emerging from July 1 to the last of September; and the second generation attacking from the middle of July to October 1 and overwintering in all stages.

This interpretation seems very unsatisfactory to the writer because it does not recognise the apparent fact that some of the infestation goes through three generations in a year, or at least two and one-half; and also because the abnormal spread of each generation makes a life history chart of this kind of little value for use in experimental studies, especially where the determination of the total beetle population is desired. It seems more accurate to separate the beetle population into two groups, one group, consisting of only about 15-20% of the total infestation, with three generations, in 1928, and the main group, which includes the balance of the infestation, with two. Further study will be required to determine whether these two groups retain their identity from year to year or only for one year, intermingling over a period of years in response to differences in temperature in different trees or in different parts of the same tree, where they happen to attack.

In Chart 1 we have separated the periods of attack and emergence into two groups, and two and three generations respectively, as indicated above. Generation I of the partial group made attacks between May 15 and June 5. Most of the trees attacked by this early emergence were large, overmature trees which had been weakened by a partial attack, in the preceding fall or the early spring, by Ips emarginatus or D.monticolae or both. The emergence from these trees began about July 5 and continued to August 1. The latter part of this emergence would attack too late to complete another generation the same year, and so would fit into the second generation of the main

group. Generation II attacks from the partial group occurred between July 5 and July 20, and emergence began about September 10. Part of the brood in these trees, especially aroundthe base, was delayed and overwintered as mature larvae. Most of the brood emerged between September 10 and October 1 and made a generation III attack during the latter part of September and October. The broods from these attacks would overwinter as parent adults, eggs and larvae, and so would emerge too late to produce more than two generations the following year.

The first-generation trees of the main group were attacked between June 10 and June 25. Most of these attacks were complete over the main trunk, and fairly large ~~trees~~ groups of trees were typical of this generation. The emergence began about July 25 and continued to about September 1. The main second-generation attacks occurred between August 5 and September 1. Most of these broods reached the large larval stage before development stopped for the winter.

It is not known whether all the brood from the main group will emerge and attack early enough to produce three generations in 1929, or if only a part of the earliest emergence will be able to do this, thus limiting the main group to only two generations again in 1929. It is certain that there are more than two annual generations, but whether there are only two and one-quarter generations as a result of themmore rapid development of 15 to 20 per cent of the total infestation, or two and one-half generations, has not been determined. If there are two and one-half generations for each of the two groups, we would expect that one group would have two generations one year and three the next, while the other group alternated with it, having two generations when the first had three and vice versa. If this is the case we should have three generations of the main group in 1929. This will be determined during the coming field season. Climatic factors, temperature especially, are undoubtedly important, and may cause variations from year to year which will make it impossible to work out any satisfactory life history except for one season.

Summary

Life history studies of D.brevicomis in Oregon and California show a difference in the rate of development and the number of generations in different localities. This probably depends principally on the sum of effective temperatures for any locality. Keen found that this beetle has approximately two and one-half generations per year in the vicinity of Ashland, Oregon, and Person found that it had three complete generations per year at Northfork, Calif.

Studies were begun in the Modoc area in 1928 to determine the number of generations in that area. Records were taken from 32 trees throughout the summer, showing either first attacks or first emergence or both for each tree. The development of the broods was followed quite closely on five of these trees from attack to emergence.

A complicated mixture of generations was found, which makes it difficult to determine accurately the number of generations for any season. On the basis of the 1928 records the beetle population was separated into a main group which included about 80 per cent of the total infestation, and a partial group, comprising the balance of the infestation. The main group had only two complete generations in 1928, while the partial group had three.

On the basis of one season's study it could not be determined whether the two groups retain their identity and have two and three generations respectively in alternate years, or if the partial group is merely a small part of the main group that because of more favorable conditions for development is able to complete three generations while the main group completes only two.

Photo No. 1 - Type of rearing cage used at Buck Creek Ranger Station for bark infested by western pine beetle and clerids.

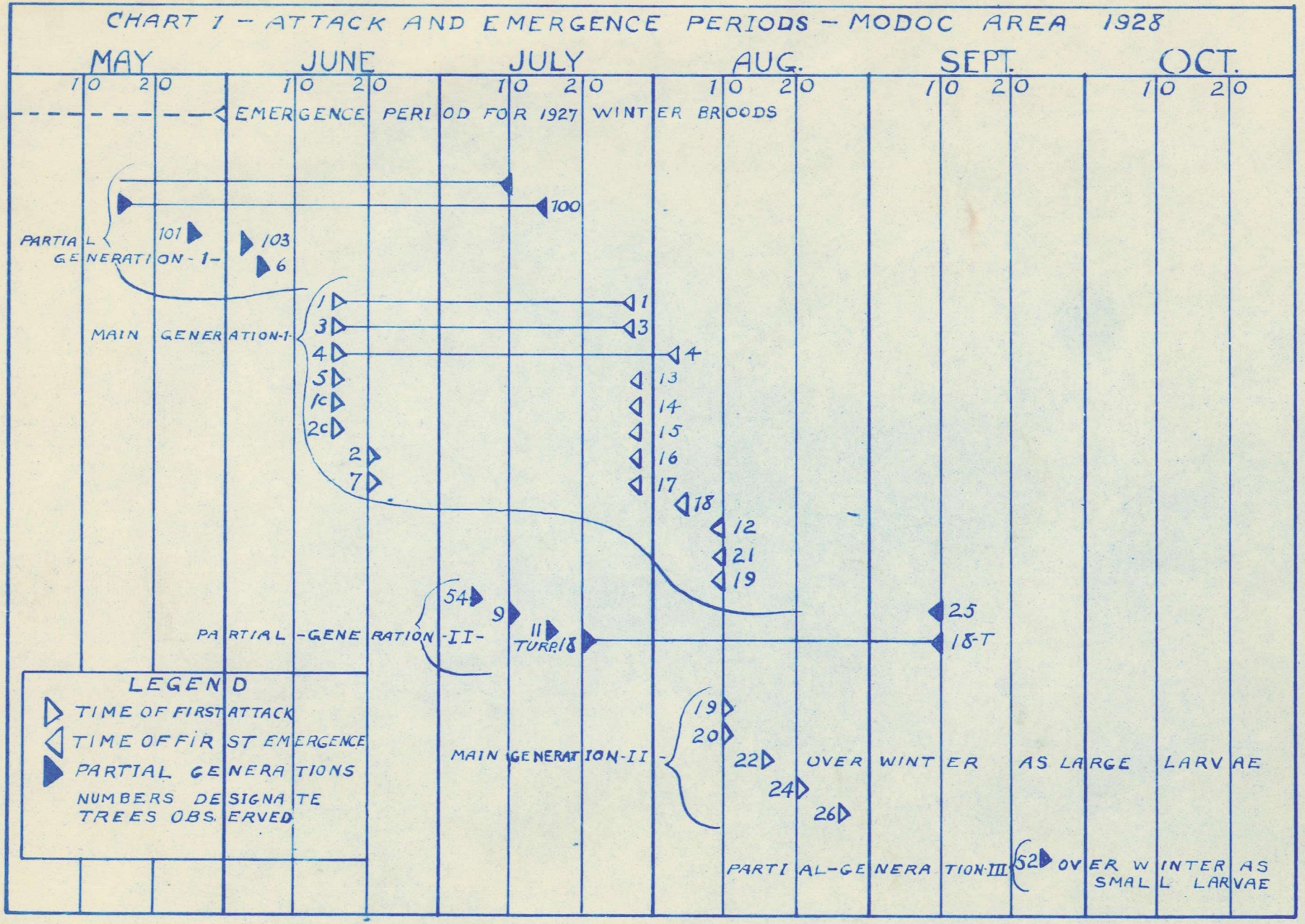
CHART 1 - ATTACK AND EMERGENCE PERIODS - MODOC AREA 1928
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
1 0 2 0
EMERGENCE PERIOD FOR 1927 WINTER BROODS
100
PARTIAL GENERATION -1-
101
103
6
MAIN GENERATION-I-
1
3
4
5
1c
2c
2
7
1
3
4
13
14
15
16
17
18
12
21
19
25
54
9
11
PARTIAL-GENERATION-II-
TURP.18
18-T
LEGEND
TIME OF FIRST ATTACK
TIME OF FIRST EMERGENCE
PARTIAL GENERATIONS
NUMBERS DESIGNATE TREES OBSERVED
19
20
MAIN GENERATION-II-
22
24
26
OVER WINTER AS LARGE LARVAE
PARTIAL-GENERATION-III-
52
OVER WINTER AS SMALL LARVAE